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Study of Flows Arising from the Torsional Oscillations of Horizontal Disk in an Inhomogeneous Fluid

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Abstract

The high-resolution schlieren visualization of the flow pattern in the stratified fluid near torsional oscillated horizontal disk is performed. Large-scale internal waves, adjacent eddy currents and fine-structure components of the vortex is studied.

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Keywords: internal waves, stratifies fluid, vortex.

Study of waves and vortices is one of the traditional areas of classical fluid mechanics remain actual during the last centuries [1]. Interest in the subject is supported by practical, technological and environmental applications, such as flow control to reduce dissipation, the study of patterns of transport of pollutants in the environment [2 – 4]. Practical problems stimulate the development of mathematical models that adequately describe the natural processes with the actual properties of fluids and the effect of external dynamic factors.

Earth's atmosphere and hydrosphere are complex environments with inhomogeneous distributions of the composition and concentration of solutes or suspended solids, temperature, pressure. Action-force leads to a redistribution of matter and the formation of stratification, that is, to increase the density of the medium in the preferred direction.

The aim of this work is the study of the flow pattern around a horizontal disc committing torsional oscillations around the vertical axis in a continuously stratified fluid.

The experiments were performed in a laboratory pool size 70×25×70 cm filled continuously stratified $NaCl$ salt solution. Kinematic viscosity of the solution differs insignificantly from the viscosity of water ν = 0,01 cm^2/s. As a source of disturbances in the medium used of the stainless steel and Plexiglas disk radius of 3, 6, 10, 14 or 18 cm and a thickness of 1, 3 or 10 mm.

Disk is installed on the shaft mechanically connected to the electric motor through reduction gearing. The am-

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plitude of oscillations regulated mechanically. Experimental setup is shown in Fig. 1.

Observation flows and internal waves in the fluid carried through the side windows using the schlieren instrument IAB-451 method of "vertical slit-thread" and their registration is photo and video cameras [5]. The index of refraction a solution of sodium chloride is associated with the density of the linear relation. Simultaneously on the shadow picture profiles fixed horizontal velocity components are rendered fluid hydrodynamic wake of freely immerse sugar crystals [6].

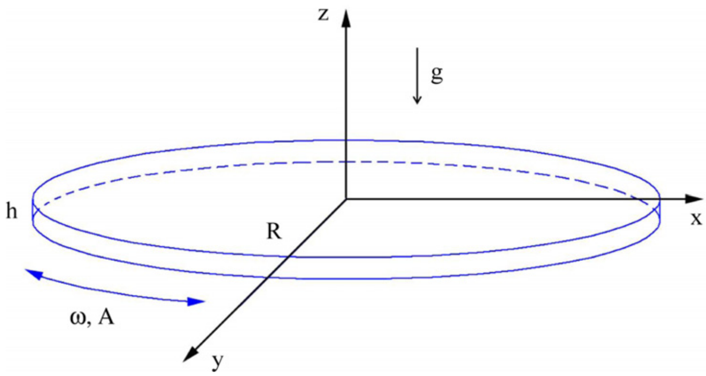


Fig. 1. The experimental setup

Measuring the amplitude of the internal waves carried conductivity probe, whose signal was recorded on a recorder or a personal computer. The sensor is the end face of the capillary diameter of 0.8 mm, into which you inserted electrode of a platinum wire. The sensor is calibrated before each experiment by the "rise – immersion" in order to determine the vertical displacement of the particles in the internal wave.

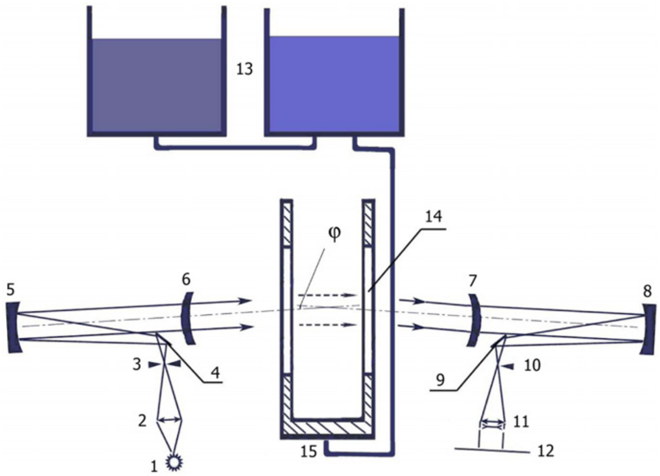


Fig. 2. Optical scheme of the experimental setup

Optical scheme of the experimental setup is shown in Fig. 2. The main element is the pool 14, the side walls of which are high-quality optical windows that do not distort the passing light waves fronts. Filling the pool of stratified fluid performed by successive displacement below using of hydraulic system under the traditional scheme, which includes two storage tank 13, a mixer and connecting hoses with shut-off control valves 15.

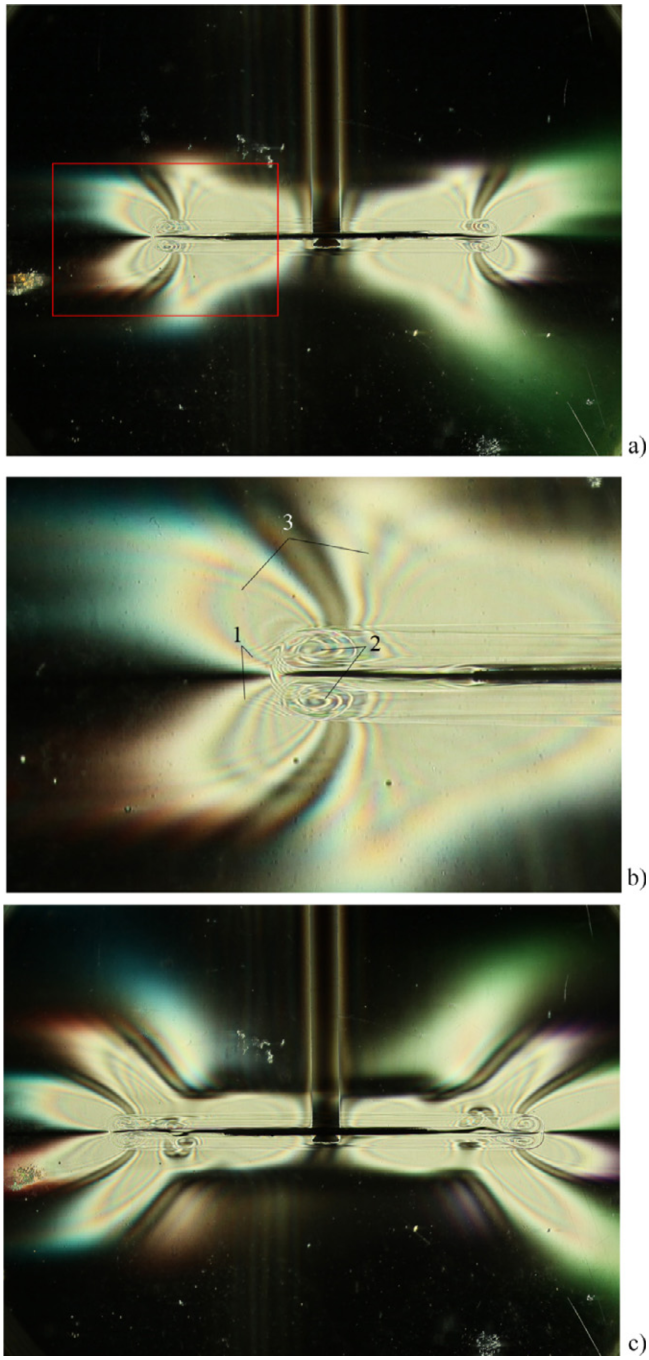
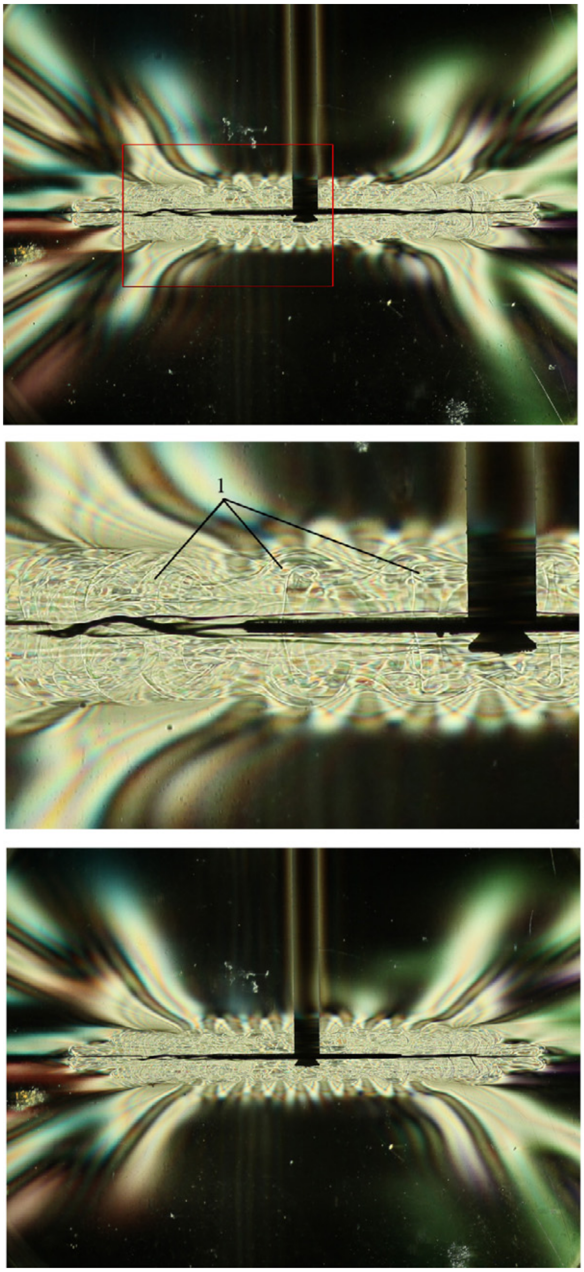


Fig. 3. Evolution of perturbations near the edge of the oscillating disk radius of $R = 3cm$ and thickness of $h = 1.2\ mm$, $N = 1.5\ s^{-1}$ $\omega = 0.23\ s^{-1}$. (a)– toroidal vortex breakdown from edge of the disk $A = 4\ \pi$; (b)– specific details of the flow $A = 4\ \pi$; (c)– distortion in the vortex $A = 7/2\,\pi$.

Optical system (1 – 12) includes: a light source 1, a condenser 2, lighting slit 3, flat rotating mirrors 4, 9, directing the light beams on the main spherical mirror 5, 8; corrective meniscus 6, 7; visualizing diaphragm 10, an optical system image converter 11, which builds an image of the flow pattern in the image plane 12.



a)

b)

c)

Fig. 4. The collapse of a toroidal vortex near the disk radius of $R = 3\,cm$ and thickness of $h = 1.2\,mm$, $N = 1.5\,s^{-1}$, $\omega = 0.23\,s^{-1}$. (a, b) ring system $A = 4\pi$ (c) distortion of the rings $A = 7/2\pi$.

After filling the pool the density profile and the frequency buoyant frequency is determined by density marks method [6]. In these experiments the buoyancy period is equal to T_b = 4.5 s. Then the generator of internal waves activated and pattern of disturbances recorded. The parameters of the internal waves are measured after the stabilization period, when the picture for a long time does not change. Duration of a single experiment varies from several minutes to several hours.

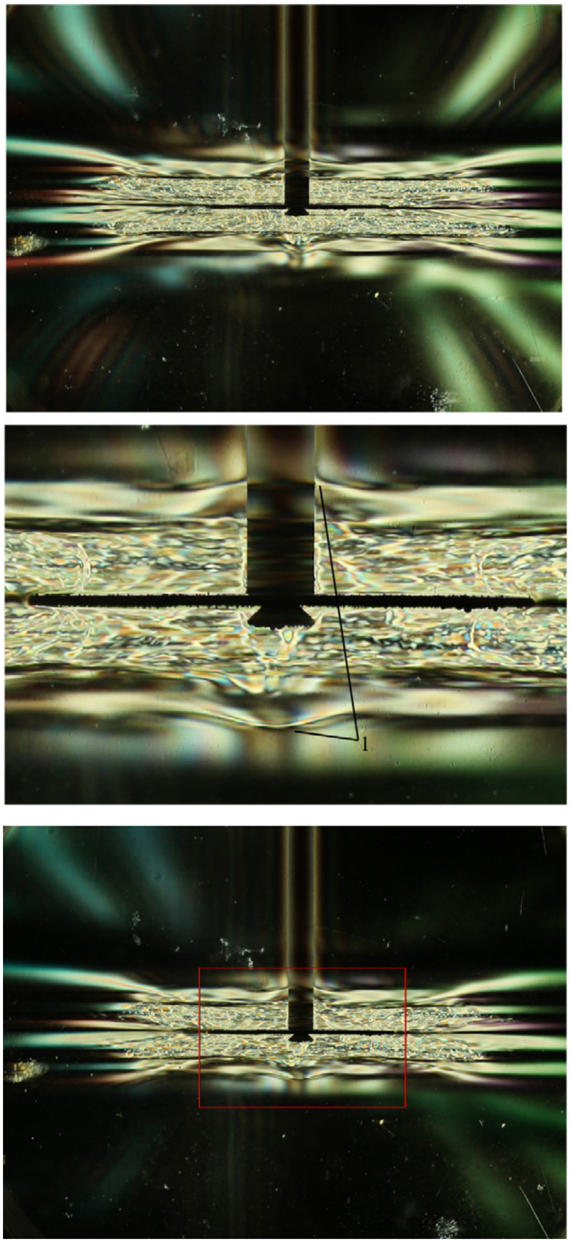


Fig. 5. Relaxation of the fluid flows around the disk radius of $R = 3\,cm$ and thickness of $h = 1.2\,mm$. $N = 1.5\,s^{-1}$, $\omega = 0.23\,s^{-1}$, amplitude (a) $A = 4\pi$, (b, c) $A = 7/2\pi$,

The initial stage of flow near the edge of the disc committing torsional oscillations is shown in Fig. 3. In the first half-cycle from the edge of the disc breaks dual toroidal vortex ring, this extends deep into the fluid along the horizontal plane of Fig. 3a. At this stage, a fast-moving vortex is a source of internal waves and associated leading disturbances.

The flow pattern in the vicinity of the front edge of the vortex is shown in Fig. 3b. Here, in addition to the double vortex two clearly visible typical flows for moving in a stratified fluid solid bodies, such as blocked liquid

1 (system of thin inclined stripes extending from the vortex into the undisturbed fluid) and the associated internal wave 3.

Over time, the movement of the vortex slows down and the vortex trail become distorted Fig. 3b. These distortions develop over time into a secondary vortex, which then develop in a reverse fluid flow from edge of the disk back to the disk axis.

At given parameters of movement in the second half-period oscillations of the disc is another runaway double toroidal vortex breaks up into a system of vortex rings strung on a disc edge Fig. 4. For other flow parameters observed breaking as an earlier (first), and more recent vortex rings.

New rings are combined with pre-existing elements of the flow around the disk Fig. 4. Here we can see evolve compared with Fig. 3 system of internal waves and disrupt the remnants of the first vortex.

Vortex ring 1 close-up shown in Fig. 4b. Here you can see that the ring is not complete since near the disk they are not closed in the sector of about 60°. According to the observed region the total number of vortex rings was 33 – 36.

Developing, the rings are also broken down into a vortex pair, located symmetrically about the plane of the disk Fig. 4. Broken up into a ring system vortex is a source of intense unsteady internal waves. In Fig. 4 you can see two sets of internal waves, located at different angles corresponding to the different half-periods of the oscillations. After a full stop disk size of the mixed fluid under the influence of buoyancy was reduced in the vertical direction Fig. 5a, b. System of periodic internal waves quickly attenuate and passed into the dissipative-gravity waves (almost horizontal lines outside the mixed region). While there was the formation of hanging stratification breaks 1 in an area where previously observed only wave motion Fig. 5c.

These experiments showed that the currents generated by an oscillating disc, have a complex spatial structure, including and wave and eddy components. Minimum length scale have high-gradient envelope on the boundary between vortex and wave.

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References

[1] Landau LD, Lifshitz EM. *Course of Theoretical Physics V. 6 Fluid Mechanics*. Oxford: Pergamon Press; 1987.

[2] Chashechkin YuD, Bardakov RN, Shabalin VV. The regular fine structure of flows in a drying drop of a suspension of quartz nanoparticles. *Doklady Physics* 2011;**56**(1):62 – 4.

[3] Chashechkin YuD, Mitkin VV, Bardakov RN. Downstream and soaring interfaces and vortices in 2-D stratified wakes and their impact on transport of contaminants. *Nonlinear processes in Geophysics* 2006;**13**:1 – 8.

[4] Chashechkin YuD, Bardakov RN, Zagumennyi YaV. Numerical analysis and visualization of fine structures of the fields of two-dimensional attached internal waves. *Phys. Oceanogr.* 2011;**20**(6):397 – 409.

[5] Smirnov SA, Chashechkin YuD, Il'inykh YuS. High-accuracy method for measuring profiles of buoyancy periods. *Meas. Tech.* 1998;**41**(6):514 – 9.

[6] Chashechkin YuD. Schlieren visualization of a stratified flow around a cylinder. *J. Visualization* **1**(4):345 – 54.